Optically-coupled monolithic DFB lasers for the generation of an optically-carried microwave local oscillator

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Abstract: We report the experimental realization of a photonic oscillator based on dedicated monolithic dual-wavelength DFB lasers. The oscillator is locked to a master RF synthesizer using an all-optical feedback loop. A [3-10] GHz tuning range is reported, with a phase noise level lower than –55 dBrad^2/Hz at 10 Hz from the carrier, instrument-limited.

1. Introduction

The potentialities of optical heterodyning for photonic oscillators are now firmly established, the optically-carried microwave signal being provided by the beat note between two laser modes. Active phase locking to an electronic local oscillator (LO) using phase-locked loops have been shown to transfer the spectral purity of the LO to the beat note [1,2]. However, such architectures inherently need a way to tune the frequency difference electronically. Conversely, optical injection locking schemes are free from electronics and it has been recently proved that dual-frequency diode-pumped solid-state lasers can be locked to an external LO by using frequency-shifted optical feedback [3,4]. However, optical injection in rare-earth lasers presents a small locking range. As semiconductors are well known to be sensitive to injection with a large locking range, we choose here to use DFB lasers submitted to intensity modulated optical feedback by using an electro-optic modulator (EOM) [5].

2. Experimental setup

The optical source [6] at 1.55 µm consists in two 2.5 mm-long monolithic DFB semiconductor lasers (see Fig. 1). Both frequencies $\nu_{1,2}$ can be tuned independently using the bias currents $I_{1,2}$. The two output beams are coupled into a lens fiber and a 20/80 coupler. The 26m-long feedback loop contains either a Mach-Zehnder intensity modulator (EOM, BW = 10 GHz, modulation depth 80%) or a frequency shifter (FS), driven by a synthesizer which provides a frequency reference f_{LO}. Next, an Er-doped fiber amplifier (EDFA, 30 dB gain) and a programmable attenuator allow controlling the feedback power. An optical circulator closes the loop. The power sent back to the DFBs is monitored from one output of the coupler. The other output provides the useful output beam, whose beat note is analyzed by a 40 GHz BW photodiode followed by an electrical spectrum analyser.

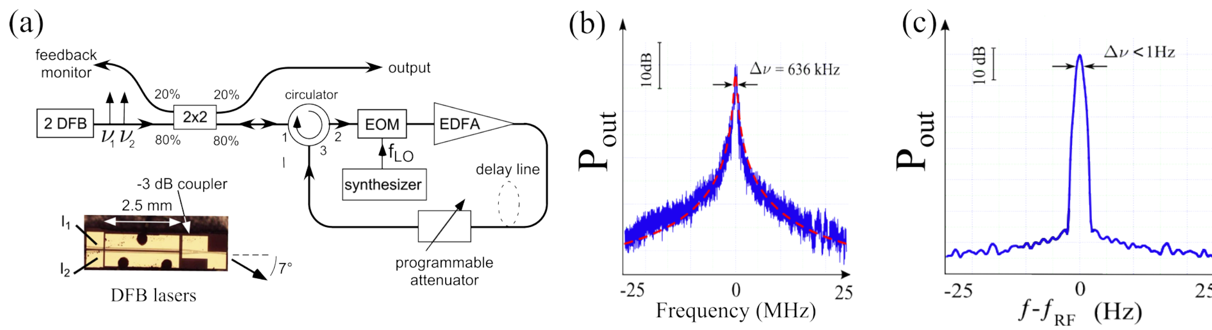

Figure 1 : (a) Experimental setup. (b) RF spectrum of the free running beat note. RBW: 30 kHz, span: 50 MHz. Solid line: measured data. Dashed line: Lorentzian fit. (c) RF spectrum of the beat note with optical feedback. RBW: 1Hz, span: 100Hz.

3. Results

The typical power coupled into the fiber is 1mW. In the free running regime, the frequency difference $\Delta\nu = \nu_1 - \nu_2$ is finely tunable from 0.3 up to 15 GHz by sweeping the bias current of one DFB. The –3dB linewidth of the beat note is 630 kHz under typical conditions (Fig. 1(b)). When the optical feedback loop is closed, the -3dB linewidth of the beat note is less than 1Hz, instrument limited (Fig. 1(c)). Furthermore, the laser remains locked for several hours. The beat note can be locked from 3 GHz to 10 GHz, the lower boundary being set by the relaxation oscillations frequency, and the upper one by the electronic amplifier for the EOM. In the experiments described below, the frequency of the beat note is 7.3 GHz. Fig. 2(a) reports the locking range as a function of the feedback level η, defined as the ratio of the amplitude of the reinjected optical field with respect to the laser output optical field. We observe that when the feedback level goes from 0.02 to 1.2, the locking range increases linearly, as in master-slave injection locking. Moreover, a locking range as large as 1 GHz can be demonstrated.

When using an EOM, a certain amount of self-injection is unavoidable. Indeed, not only the frequencies $\nu_1 \pm f_{LO}$ and $\nu_2 \pm f_{LO,}$ but also ν_1 and ν_2 are reinjected. Since this fact could lead to instabilities, we have replaced the EOM with a FS and compared the phase noise spectrum in the locking regime. As shown in Fig. 2(b), the phase noise coincides with the detection noise floor in the [10 Hz – 1 MHz] frequency range, showing that our oscillator has a better stability than the available measurement apparatus, both with the MZM and the FS. It can thus be concluded that, at least in the explored range of parameters, self-injection does not seem to play a significant role in the locking dynamics.

To check the insensitivity of the locking to the length of the loop, we inserted a delay line (700m, $\tau = 3.5\mu s$) in the feedback loop. We could hardly measure a difference in the phase noise between these two cases. We have also checked the frequency agility of the system, i.e. the time it takes to lock after an abrupt change of the LO frequency, and found that it is limited by the length of the loop. For a loop of 26 m, the response time is ~ 0.1 µs.

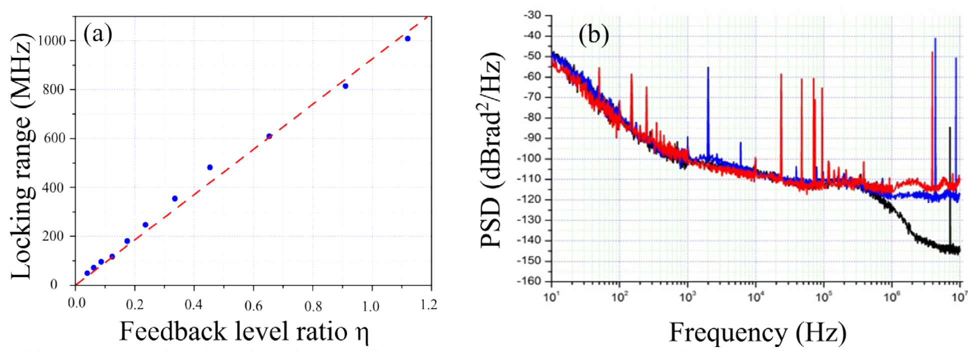

Figure 2 : (a) Locking range as a function of the feedback level. Dots: measured data. Dashed line: linear fit. (b) Phase noise spectra. Red: with the EOM in the feedback loop. Blue: with the FS. Black: noise floor.

4. Conclusion

We have built a photonic oscillator based on monolithic DFB semiconductor lasers, driven by a master microwave synthesiser. The oscillator is stable, finely tuneable, and displays a large locking range and a low phase noise level. Our scheme could be extended to millimeter-wave frequencies [7] by using, e.g., inloop fast EOM or harmonics from a nonlinear modulator [8].

5. References

[1] Gliese U., et al, "A Wideband Heterodyne Optical Phase-Locked Loop for Generation of 3-18 GHz Microwave Carriers," *IEEE Photonics Technol. Lett.,* 4, (8), pp. 936-938, 1992.

[2] Rolland A., Frein L., Vallet M., Brunel M., Bondu F., and Merlet T., "40 GHz photonic synthesizer using a dual-polarization microlaser", *IEEE Photon. Technol. Lett.,* 22, pp. 1738-1740, 2010.

[3] Kervevan L., Gilles H., Girard S., and Laroche M.: "Beat-note jitter suppression in a dual-frequency laser using optical feedback", *Opt. Lett.*, 32, (9), pp. 1099-1101, 2007.

[4] Thévenin J., Romanelli M., Vallet, M. Brunel M., and Erneux T., "Resonance assisted synchronization of coupled oscillators: frequency locking without phase locking," *Phys. Rev. Lett.* 107, (10), 1041, 2012.

[5] Wang L., Romanelli M., Van Dijk F., and Vallet M., "Photonic microwave oscillator based on monolithic DFB lasers with frequency-shifted feedback", *Elec. Lett.*, 50 (6), 451, 2014.

[6] Van Dijk F., Accard A., Enard A. , Drisse O., Make D., and Lelarge F.: "Monolithic dual wavelength DFB lasers for narrow line width heterodyne beat-note generation", *Proceeding of 2011 IEEE International Topical Meeting on Microwave Photonics*, p 73, 2011.

[7] Carpintero G. et al.: "95 GHz millimeter wave signal generation using an arrayed waveguide grating dual wavelength semiconductor laser", *Opt. Lett.*, 37, pp 3657-3659, 2012.

[8] Rolland A., Loas G., Brunel M., Frein L., Vallet M., and Alouini M. "Non-linear optoelectronic phase-locked loop for stabilization of opto-millimeter waves: towards a narrow linewidth tunable THz source", *Optics express*, 19, pp 17944-17950, 2011.